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IN EUROPE DUE TO THE CHERNOBYL ACCIDENT



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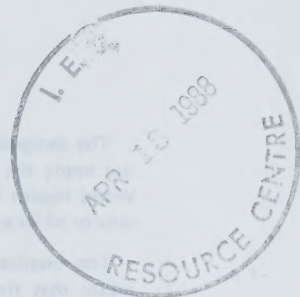
**ASSESSMENT OF RADIATION DOSE COMMITMENT
IN EUROPE DUE TO THE CHERNOBYL ACCIDENT**

**Report on a WHO meeting
Bilthoven, 25-27 June 1986**

Editors: *Erich Wirth*
Nicolaas D. van Egmond
Michael J. Suess

Published on behalf of the

**WORLD HEALTH ORGANIZATION
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in cooperation with the

**WHO Collaborating Centre on Environmental Health at the National Institute of
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and the

**WHO Collaborating Centre for Quality Control and Assurance and for Studies on the Efficacy and
Efficiency in the Medical Application of Ionizing Radiation and Radionuclides at the
Institute for Radiation Hygiene of the Federal Health Office (BGA) Neuherberg, Federal Republic of Germany**

April 1987

ASSESSMENT OF RADIATION DOSE COMMITMENT IN EUROPE DUE TO THE CHERNOBYL ACCIDENT

Report on a WHO meeting
Zürich, 25-27 June 1986

Editors: Fred Wolff
Hans-Joachim A. von Eschwege
Michael A. Jones

Published on behalf of the
WORLD HEALTH ORGANIZATION
Regional Office for Europe

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Note from the publishers

The meeting in Bilthoven was held on 25 to 27 June 1986 to make a preliminary assessment of the radiation dose commitment in Europe and to compare meteorological simulation models. Today, one year after the accident, a much better data base and more precise dose estimates are available. Yet we are still publishing this report as we feel that it is of interest to compare the first dose assessments with later ones to get an idea of the reliability of early dose predictions. Consequently the figures in the report reflect the state of knowledge in June 1987. Since last summer data from many extensive measuring programmes have been available to compile maps showing the local dose rates for most European countries. These now may be compared with the early meteorological calculations. This comparison should help scientists to improve their prognostic statements after widespread accidental releases.

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PREFACE

As part of the immediate follow-up to the accident on 26 April 1986 at the nuclear power plant at Chernobyl, USSR, an expert consultation was organized by the WHO Regional Office for Europe on 6 May 1986 to provide interim guidance on the effects of the accident outside the USSR. Moreover, the Regional Office acted as a clearinghouse for information on levels of radiation and public health actions taken by European countries. This information was widely circulated, first on a bi-weekly and then on a weekly basis throughout the period of the emergency.

At the suggestion of the National Institute of Public Health and Environmental Hygiene, Bilthoven, Netherlands, and the Institute for Radiation Hygiene of the Federal Health Office, Neuherberg, Federal Republic of Germany, both of which are WHO collaborating centres, a working group was held from 25 to 27 June 1986 to make a preliminary assessment of radiation dose commitment in Europe due to the Chernobyl accident. While the results were recognized as tentative, the experience proved to be both stimulating and productive, and it is hoped that this report of the meeting will prove useful, pending more comprehensive information which will become available in due course.

I would like to express warm thanks to the two sponsoring institutions and to all the scientists who wholeheartedly devoted themselves to a very difficult task at a time when all parties concerned were under extreme pressure in the aftermath of the Chernobyl accident.

J. Ian Waddington

Director

Environmental Health Service

WHO Regional Office for Europe

1. INTRODUCTION

On 6 May 1986, the WHO Regional Office for Europe convened a consultation of experts to evaluate the immediate problems caused in various European countries by the Chernobyl nuclear reactor accident of 26 April 1986. The consultation did not attempt to draw any conclusions on the long-term impact of the accident because of the few data available on the deposition of cesium-137 and its geographical distribution.

In the following weeks more measurement results had become available from the various countries, and the dispersion of radioactive material over Europe was modeled by means of trajectory studies. Research groups from the Netherlands, the United Kingdom and the United States applied large-scale simulation models to reconstruct the concentration and deposition pattern of radionuclides over Europe.

Given this newly obtained measurement and model information, the WHO Regional Office for Europe subsequently organized a Working Group of experts in such fields as radiation medicine, health physics, agriculture and food, public health and meteorology, together with representatives of international and intergovernmental organizations to make a preliminary estimation of the population dose in Europe resulting from the Chernobyl nuclear accident. The meeting was held in Bilthoven, Netherlands, from 25 to 27 June 1986, and was organized in cooperation with two WHO collaborating centres at the National Institute of Public Health and Environmental Hygiene at Bilthoven, Netherlands, and the Institute for Radiation Hygiene of the Federal Health Office at Neuherberg, Federal Republic of Germany.

The purpose of the meeting was to review the concentrations and depositions of radionuclides in view of the prevailing meteorological conditions and by use of appropriate predictive models. Consequently, an attempt was made to estimate the resulting contamination of foodstuffs and, tentatively, to predict the population dose from external exposure, inhalation and ingestion.

The meeting was attended by 26 participants from 15 countries. Besides the secretariat of the World Health Organization, FAO, IAEA, UNSCEAR, WMO

and CEC were also represented. A list of participants is given in Annex 3. Dr. B.C.J. Zoeteman was elected Chairman, Dr. A. Kaul was elected Vice-Chairman, and Mr. N.D. van Egmond and Dr. E. Wirth were appointed as Co-Rapporteurs. Dr. M.J. Suess acted as Scientific Secretary.

After a plenary session with short statements from the participants on the situation in their respective countries and a discussion on the working procedure of the meeting, three subgroups were formed (Annex 2). Subgroup 1 on meteorological models and radioactive material deposition was directed to the reconstruction of concentration and deposition patterns over Europe by evaluating the results of large-scale simulation models, in combination with measurement results. Subgroup 2 on radionuclide uptake by foods and exposure routes to man was to make a quantitative assessment of the dose from inhalation and ingestion as a result of the uptake of deposited material in foodstuffs, and an evaluation of the external exposure from deposited radioactive material. Subgroup 3 on radiation exposure to the population was to assess the overall radiation dose due to the Chernobyl release using the results of subgroups 1 and 2.

2. HISTORY OF THE ACCIDENT: THE LOCAL SITUATION

The Chernobyl nuclear power station is located approximately 130 km north of Kiev. It has four reactor units and one (number 5) under construction. The first reactor of this type was built near Leningrad and started operating in 1973.

The reactor unit is the "channel" type, graphite-moderated and light-water cooled. It uses low-enriched uranium-235 (1.8-2.0%). Water boils in the channels, and a direct steam cycle to the turbine is used. The channel-type reactor provides the possibility of changing part of the irradiated fuel during operation.

On 26 April 1986, during a planned test procedure in which the power was reduced to 7% of the maximum, the reactor of the number four power unit suddenly increased in power. During the intensive increase of power, the cooling water evaporated and a large quantity of steam was formed. The positive vapor void effect further accelerated the increase of power. The

steam began to interact with zirconium, causing the formation of hydrogen and a subsequent explosion. An extensive fire in the number four unit of the Chernobyl nuclear power station followed this explosion. The reactor building, equipment and a part of the core were significantly damaged. A substantial amount of radioactive material (approximately 3% of the total amount of radioactive materials in the active zone according to preliminary assessment - basically fission products) was released to the atmosphere. The reactor fire ended on 5 May 1986. Two people died during the accident (one from extensive burns, the other from acute physical injuries caused by falling equipment). In total, 300 people were hospitalized with different types of acute radiation syndrome, of whom 29 subsequently died.

To prevent unnecessary irradiation of persons (workers involved in the accident and the population of the nearest small towns and villages), preventive measures were introduced: potassium iodide tablets were widely distributed inside as well as outside the 30-km zone several hours after the beginning of the accident. Later, when the level of external irradiation began to increase, the people in the villages and small towns located at a distance of up to 30 km from the nuclear power station were evacuated. Over 100 000 people were evacuated. Monitoring of radioactive contamination was started in several regions of the Ukraine, Byelorussia, and Moldovian and Russian Federation Republics where radioactive fallout was detected. The levels of external irradiation and radioactive contamination of various foodstuffs were kept under constant control with the aid of a meteorological radiological network. The Ministry of Health of the USSR regularly received information on the external exposure rate and measurement results of the content of radionuclides in milk and some other foodstuffs by telephone or telex from different locations in the contaminated regions.

Temporarily accepted levels of radioactive contamination of various foodstuffs were introduced by the Ministry of Health in the USSR to limit the levels of internal irradiation.

The main zones of soil contamination after the accident were to the west, northwest and northeast of the Chernobyl plant, and to a lesser extent in

the southern region. Radiation levels near the plant exceeded 1 mGy/h. To the west, the maximum radiation levels 15 days after the accident were 50 μ Gy/h at a distance of 50-60 km from the accident zone. Similar levels were detected in the northern direction at a distance of 35-40 km. In Kiev, the radiation levels at the beginning of May reached 5-8 μ Gy/h.

Later, these levels decreased gradually. Since 9 May, measurement data from 7 stations in the USSR located in Oster (north of Kiev), Leningrad, Riga, Vilnyus, Brest, Rakhov and Kishinev (near the Romanian border) were telexed daily to IAEA and WHO.

One month after the accident, the external exposure rate at locations in the northwest regions along the border of the USSR were close to that of normal background radiation (0.1 μ Gy/h). A slight increase of the levels was observed in the southwest regions at Rakhov and Kishinev, with levels of 0.2-0.4 μ Gy/h in mid May.

3. METEOROLOGICAL ANALYSIS AND SIMULATION MODELS

The dispersion over Europe of radioactive material released from the Chernobyl reactor was reconstructed by several research groups and institutes. These activities included qualitative and quantitative analyses of the meteorological situation in the following days and weeks. These studies involved the following activities:

- A trajectory analysis was made by Ch. Persson from the Swedish Meteorological Institute; the results of this study were presented in the report of the WHO consultation on May 6.¹

¹ Chernobyl reactor accident: report of a consultation on 6 May 1986. Copenhagen, WHO Regional Office for Europe, 1986 (unpublished document ICP/CEH 129) (in English, French and German).

- The U.S. Lawrence Livermore Laboratory applied the ARAC-ADPIC model to describe quantitatively the dispersion over Europe and the Northern Hemisphere; however, this model does not take into account the wet deposition of radioactive particles and gas.¹
- The MESOS model, developed by H. ApSimon from Imperial College, London, has been applied to compute maps of concentrations and depositions over Europe.²
- The numerical GRID model, developed by N.D. van Egmond from the National Institute of Public Health and Environmental Hygiene, Bilthoven, Netherlands, in collaboration with the Royal Netherlands Meteorological Institute, was applied for the computation of concentration and deposition maps for Europe.³

The results of trajectory studies were compared with those of modelling studies, and the performance of the models was evaluated by comparison with measurement results. Attention was also focussed on the MESOS and the GRID models, as these models compute quantitatively concentration and deposition patterns. Apart from the mechanism for transport of material, the models also differ with respect to the construction of wind fields and rain patterns. With respect to dry and wet deposition, only minor differences exist between the two models.

The models can be seen as an instrument for the interpolation and extrapolation of available measurement results. In the absence of detailed information, the absolute source strength and the source strength evolution in time are estimated by comparing the model calculations with measurement results. Herein the measured concentrations in air play a dominant role, as the spatial gradients of concentration are small in comparison to the gradient of nuclide depositions which are strongly influenced by local

¹ Gudiksen P. ARAC preliminary dose estimates for Chernobyl reactor accident. Lawrence Livermore National Laboratory, CA, USA, 1986.

² ApSimon H.M., Goddard A.J.H. and Wrigley J. Long range atmosphere dispersion of radioisotopes. The MESOS Model, Atmospheric Environment 19 (1985) 99-111.

³ Egmond N.D. van & Kesseboom H. Mesoscale air pollution dispersion models. I. Eulerian GRID model, Atmospheric Environment 17 (1983) 257-265.

rainfall and especially by convective thunderstorms. Consequently, the air concentration measurements are considered to be more suited for validating the reconstruction of the nuclide transport in space and time. Depositions are directly related to air concentrations and rainfall. Depositions accumulated over a sufficiently large area should approach total emission. From these "budget" considerations and an eventual agreement between calculated and measured air concentrations, the validity of the associated deposition pattern may be deduced. Finally, wet deposition measurements may be used to judge the order of magnitude in which local (wet)depositions deviate from average depositions in an area as reconstructed by the models, taking into account their limited spatial resolutions.

4. SOURCE CHARACTERISTICS

For both the MESOS and GRID models, an acceptable fit between measured and modelled activity concentrations was found at a total emission of 6-8 10^{17} Bq for I-131 and 5×10^{16} Bq for Cs-137. In terms of the USA WASH 1400 report¹ (which is mainly based on reactor types different from that in Chernobyl), this implies a total emission of 20-25% of the core content of a 1000-MW reactor after an operation time of 550 days. As the reconstruction of the concentration and deposition patterns can be seen as model-supported extrapolation of the measurement results, accurate estimation of the source strength is not strictly necessary. Nevertheless, the obtained emission estimates appear to be within a realistic range.

Given the spread of the radioactive material over various parts of Europe over time, the half-life of the source strength could be estimated, although the relative lack of measurement data for the Balkan countries decreases the accuracy of the estimate for the later part of the episode. A source strength half-life of 2 days was adopted.

The effective source height chosen was 500 m for the GRID model and was equally divided between 50 and 1000 m for the MESOS model. Sensitivity analysis did not show a major influence of the source height, except within a few hundred kilometers of the source, as the first diurnal mixing cycle dominates the vertical dispersion soon after the release.

¹ Reactor Safety Study. An assessment of accident risks in US commercial power plants, appendix VI, WASH-1400 draft, August 1974; Wash-1400 (NV REG-75/014) Final, October 1975.

In August 1986, the USSR released a report to IAEA, which included emission data specific for the accident at the Chernobyl reactor.¹ According to this report, the total emission should have been 2.7×10^{17} Bq for I-131, and 3.7×10^{16} Bq for Cs-137, which should be compared to the above-mentioned estimates of 6×10^{17} Bq and 5×10^{16} Bq, respectively. The Russian data seem to be based on the total (measured) deposition within the USSR, which would mean that these emissions are underestimated. It is concluded that the source strength estimated from the concentration measurements are in good agreement with the newly released information. The USSR report describes decay of the source from the moment of the explosion on 26 April to 6 May, which is in agreement with the assumptions made for the time evolution of the source strength in the models. However, after 1 May, a substantial increase of the emission is reported with a maximum on 5 May. The material released during these days was transported mainly to the Balkan countries, from where relatively few measurement data are currently available, as mentioned before.

5. METEOROLOGY: CONCENTRATION AND DEPOSITION PATTERNS

Given a reasonable correspondence between the models and between model results and available measurements, the transport and deposition of the Chernobyl release over Europe during the first 2 weeks after the accident were described by these model results. These results are also in agreement with the trajectory analysis which was made in an early stage by the Swedish Meteorological Institute as presented in the report in the WHO consultation of 6 May. The time evolution of the transport dispersion of the radioactive material will be discussed on the basis of daily modelled average I-131 concentration maps, in combination with cumulative deposition patterns.

¹ USSR State Committee on the Utilizations of Atomic Energy. The accident at the Chernobyl Nuclear Power plant and its consequences, August 1986 (working document for the IAEA Post Accident Review Meeting).

On 26 April, the day of the accident, the weather in Europe was dominated by a strong high pressure area over the western parts of the USSR and a low pressure area that reached from Iceland to northwestern Europe. This system maintained a southeasterly flow over the western part of the USSR, Poland, Scandinavia and Finland, transporting the material released from Chernobyl over Poland to Finland and Sweden during 26-27 April. (Fig. 1a and 1b).

On 28-29 April, the flow pattern over central Europe contained a northerly component. During rainfall in the area north of Stockholm up to the west coast of Finland, I-131 depositions from 100 to 200 kBq/m² were calculated and measured (Fig. 2a and 2b). Measurements indicated local maxima up to 1000 kBq/m² for I-131 and 140 kBq/m² for Cs-137. After the wet deposition, total exposure rates of up to 500 μ R/h were measured in Sweden and at the west coast of Finland. The deposition in Sweden seems to be 2-3 times higher than that in Finland. Also, local variations are greater in Sweden than in Finland.

The material released from Chernobyl on 26 April was at least partly transported from Scandinavia and Finland with the northeasterly flow to the central part of Europe. Additionally, newly released material was transported directly to central Europe. On 30 April, activity concentrations over central Europe were between 10 to 50 Bq/m³ for I-131 east of a cold front. During heavy rainfall in the central part of Austria and in the southern part of the Federal Republic of Germany, I-131 depositions of more than 100 kBq/m² were calculated and measured (Fig. 3a and 3b). With the northeasterly flow and varying heights up to 2000 m, material freshly emitted from Chernobyl was transported over the Alps into Italy. On 1 May, the ridge of high pressure over France and Denmark shifted its centre to Denmark, resulting in a clockwise circulation over central Europe, transporting the previously released material from central Europe to the northwest. On 2 May, a ridge of activity concentrations in a range of 5 to 50 kBq/m² extended from the Alps over the Netherlands to Scotland (Fig. 4a). At the approach of a cold front on 3 May, precipitation in this area resulted in wet deposition in the range of 1 to 20 kBq/m² of I-131 (Fig. 4b). On 4-5 May, the deposition associated with the front shifted to the northern parts of the German Democratic Republic and the Federal Re-

public of Germany (Fig. 5a and 5 b) and continued on 6 May (Fig. 5c).

In the southern part of Europe, activity concentrations as a consequence of the early released material over the Alps increased as of 30 April. From 2-5 May northern Italy experienced a wet I-131 deposition of about 100 kBq/m². On 5 May, a wet I-131 deposition of 96 kBq/m² was reported in central Italy. This material had been released at Chernobyl on 27 April. Material released on 28 April was transported in easterly directions and did not reach southern Europe. From 29 April on, the windfield in southern Europe being mainly in a northeasterly direction, radioactive material was transported into the Balkan countries. However, by this time, the source strength used in models had already decreased. The results of the two models have been compared to measurements; in Figure 6, the time evolution of measured I-131 concentrations in air, together with the results from the GRID and the MESOS model are given for a number of European measurement stations. Despite some discrepancies in the arrival times and air concentrations, the model seems to reconstruct the general flow pattern.

To derive the inhalation dose, the time-integrated I-131 concentrations have been computed by both models; the results are presented in Figure 7. These time-integrated patterns reflect the major flow during the first days after the release; later the source strength decreased and the early released material was deposited on the ground. Consequently, the highest time-integrated I-131 levels (300-1000 Bq·d·m⁻³) were found, apart from the Ukraine, in the Baltic states in Russia, northeast Poland and Sweden. For central Europe, I-131 levels are in a range of 100-300 Bq·d·m⁻³.

The integrated cumulative deposition patterns for I-131 and Cs-137 are presented for the MESOS model, the GRID model and the available measurements in Figures 8 and 9. The simultaneous presentation of the maps for the two models shows the band width at which these computation results should be interpreted.

Apart from the Ukraine, both models indicate areas with high deposition (over 100 kBq/m² for I-131 and a correspondingly high value for Cs-137) for smaller parts of central Europe. This corresponds to areas where precipitation encountered the cloud of released material. Trajectory

calculations indicate high depositions in central Scandinavia and Finland which were not yet included in the model areas.

The results are supported by the available wet deposition measurements. In larger parts of central Europe, I-131 depositions are in the range of 50-100 kBq/m².

On sub-model spatial scales, deposition may be more than an order of magnitude higher than the grid-average values due to locally enhanced rainfall. Discrepancies between the models are found for the Balkan countries where the GRID depositions are higher than the MESOS results, due to an assumed higher emission during the later days. Measurement results suggest that the most likely depositions lie between the results from the two models.

6. CONTAMINATION OF FOOD

Iodine-131

The immediate effect of deposition was an increase in I-131 contamination, especially in milk and fresh leafy vegetables. Depending on the season, other foods were not considered to be of importance in estimating the overall dietary intake. The fallout by the end of April and in early May led to the direct contamination of leafy vegetables and grass (pasture). Approximately 10-20% of the wet deposition remained on the plants. Vegetables in greenhouses and under plastic covers were considerably contaminated by dry deposition of I-131 of up to 1000 Bq/kg in regions with high iodine-131 concentration in the air. Nevertheless, the situation varied between northern and southern Europe, depending on the advancement of the agricultural season. In the Scandinavian countries and Finland, the direct contamination of vegetables was negligible, due to the late growing season. In central and southern Europe, the highest values in leafy vegetables were found during the first days of May. A quick reduction of the I-131 concentration by radioactive decay and rapid plant growth was observed during the following weeks. Because of the short half-life of I-131, root uptake was negligible.

The concentration of I-131 in milk followed the pattern of pasture contamination. Observations indicate that a deposition of I-131 of 10 kBq/m²

resulted in a contamination of milk of up to approximately 250 Bq/l in the early days of May. Many farmers kept their cattle indoors to prevent contamination by grazing, but inhalation still accounted for a small uptake.

Cesium-137

In May and June, the situation concerning cesium was similar to that of I-131. The contamination of leafy vegetables and pastures occurred at the same ratio of I-131 to Cs-137 as in the fallout.

The situation following this period was marked by two uptake pathways of growing plants. A large part of direct Cs-137 deposition on the leaves of growing plants was taken up by the plants and a fraction was transported to fruits or grain. The other pathway, from soil via roots, is of minor importance in the first year. Thus very low levels of activity were detected in plants which emerged after the period of deposition, also in areas where deposition was high. The fruits of plants with contaminated blossoms and leaves showed much higher Cs-137 activities than plants with root uptake only.

The significance of the direct pathway depended on the advancement of the agricultural season at the time of contamination.

A significant increase in Cs-137 contamination of cow's milk was noted soon after the accident. Levels of up to 600 Bq/l were measured in highly exposed regions. By the end of a 5-week period, the concentration of Cs-137 in milk generally declined to less than 100 Bq/l and this trend was expected to continue throughout the grazing season. Towards autumn, levels increased again when cows were fed silage or hay which has been contaminated during May.

The same general considerations apply to meat, but a number of additional factors must be taken into account. The half-life of Cs-137 is longer for muscle tissue than for milk, and the concentration in meat therefore declines more slowly. The contamination of the feed components will, however, be a determining factor for estimating concentrations of Cs-137 in animal products. Beef and pork from animals which have been fed indoors with grain, silage or hay, have low concentrations of Cs-137 (between 0

and 40 Bq/kg). In meat from pastured cattle, values between 200 and 1100 Bq/kg were measured by the end of May.

Special consideration must be given to meat from game (e.g. deer, rabbits). Game animals have shown considerably higher levels of Cs-137 than domesticated animals. Reindeer are a special case because the concentration of Cs-137 in their feed may be very high. Only the southern parts of the reindeer breeding regions of Sweden and Norway were contaminated. Concentrations of Cs-137 of several thousand Bq/kg were measured in game from highly exposed regions.

In areas with a high deposition rate in freshwater of low nutrient concentration (e.g. in Austria), the concentration of Cs-137 in fish increased significantly (up to 1000 Bq/kg and more). In sea water and estuarine fisheries, levels remained much lower.

7. DOSE CALCULATIONS

7.1. General remarks on dose calculation

There were large differences in measurement procedures and the manner in which data were reported. Therefore, considerable care is needed in the interpretation of the data. To facilitate an uniform approach to estimating radiation doses in the following section, principles are described for estimating doses from external exposure, inhalation and ingestion using the available data.

7.2. Exposure pathways

Exposure of the population occurs through three main pathways: inhalation of airborne material; external irradiation from material deposited on the ground; and ingestion of contaminated foodstuffs.

7.2.1. External dose from deposition of radionuclides

Where data for a region provide external air kerma rates ($\mu\text{Gy/h}$) for a sufficient length of time, the integral air kerma can be computed. The air kerma (μGy) can be converted into the effective dose equivalent using a factor of 0.7 Sv/Gy; the effective dose equivalent will be denoted as H_E .

Where data for external air kerma are not available but deposition data (Bq/m^2) for specific radionuclides are, the air kerma for these radionuclides (i.e. I-131, Cs-134 and Cs-137) can be estimated. The disappearance rate by physical decay and migration of radionuclides into the soil, which may be important in the future, should be considered in computing the dose component from long-lived radionuclides.

The external dose depends on several parameters and assumptions, in particular for indoor occupancy, the shielding factor for structures and the leaching of radionuclides into the soil. The values for these parameters should be indicated and comments made on the selection of the values.

7.2.2. Internal dose from inhalation of radionuclides

I-131 is the principal contributor to the thyroid dose following inhalation, so that the age-dependent, committed dose equivalent has to be computed. The air concentration data provide enough information to determine the need for including other radionuclides in the calculation of the committed effective dose equivalents. For dose calculations, the activity concentration in air has to be integrated. If available, measured air concentrations (Bq/m^3) should be used for a region over a sufficient period of time. Age-dependent factors for breathing rates are to be considered.

Measurements of human thyroid activity in the first days of plume passage reflect mainly the inhalation dose and are useful for comparison with the calculated dose from air concentrations.

7.2.3. Internal dose from ingestion of radionuclides

The committed thyroid dose equivalent for 1- to 10-year olds from ingestion of I-131 and the committed H_E for children and adults, due to ingestion of Cs-137 primarily, should be computed.

The ingestion dose may be separated into three categories:

1. Ingestion activity and resultant committed H_E from measurements of food contamination from the end of April through June (i.e. approx. 60 days).
2. Ingestion activity and resultant committed H_E for intake for the rest of the initial 12-month period through March 1987 from deposition of radionuclides, representing the first growing season after the accident.
3. Ingestion activity and resultant committed H_E for intake during each successive 12-month period.

All of the above ingestion dose categories require data for regional standardized food baskets to account for local consumption patterns. An attempt can be made to estimate the effect on committed thyroid equivalents and committed H_E with food use restrictions or voluntary changes in food consumption patterns.

Examples of dose calculations are given in Annex 1.

8. RESULTS

8.1. External radiation

External radiation from deposited material can be estimated with reasonable reliability either from measured exposure rates or from measured deposition per unit area. Dose equivalent calculations need to take into account the time spent indoors and the shielding factor afforded by buildings. These will vary from country to country, but average values can be determined for each country. The estimated values of the H_E for the first year for adults range between $1\mu\text{Sv}$ in western France to $500\mu\text{Sv}$ in highly exposed regions in Poland and Sweden (Fig.10).

8.2. Inhalation

Inhalation doses can be estimated with reasonable reliability, since it is necessary only to know the measured radionuclide concentration in air and to apply standard values for age-dependent inhalation rates and dose conversion factors to obtain committed dose equivalents. These values are given in Figure 11.

The results show that inhalation has been a minor contributor to the committed effective dose equivalent, but it is a significant contributor to the I-131 thyroid dose. The doses to the thyroid were calculated using measured air concentrations for a region during the first days of the plume passage and by integrating the inhalation activity. The H_E for adults varies between 1 and $100\mu\text{Sv}$ in most parts of Europe. The corresponding dose to the thyroid is higher by a factor of 30.

8.3 Ingestion

Ingestion doses originate mainly from iodine-131, cesium-134 and cesium-137. For iodine-131, the important foodstuffs are milk and leafy vegetables. Because of the short physical half-life of this nuclide, these doses had already been fully received by the end of June. Generally, they can be estimated from concentrations that were measured in foodstuffs, the average consumption rates and the standard values of the committed dose

equivalent per unit of ingestion. The calculated doses will vary from country to country because of differences in diet and consumption pattern.

In this case, the intervention by governments in some countries and the voluntary changes in consumption patterns affected the overall intake pattern considerably. Therefore, the activity intake cannot be estimated from the contamination of food only. Factors such as washing of vegetables also contribute slightly to the lack of correlation.

Nevertheless, average values were assumed to provide a dose estimate for inhalation and ingestion for each age group within each country. In Europe, the estimated dose of I-131 to the infant thyroid ranges from 0.05 - 200 mSv (Fig. 12). When protective measures were used, the higher values could be reduced by a factor of 6. Voluntary changes in patterns of food consumption could minimize the dose.

For estimating the doses from cesium isotopes, not only must doses from ingestion of foodstuffs in the current year be considered but also the doses that will be received in the future, following long-term transfer through food chains. An accurate dose assessment in the current first year is difficult, especially because the amount of penetration of Cs-134 and Cs-137 into the plants via the leaves and their subsequent transport into the eatable parts of the plants are subject to large variations (Fig. 13). A rough estimation indicates that the H_E in the first year should not exceed 1 mSv, even in highly exposed regions. The spatial pattern of the effective dose equivalent (Fig. 14), as reported by the various countries, broadly reflects the overall deposition patterns as given in Figures 8 and 9. The variation in exposure due to differences in the food basket were considered to be substantial but of less importance than those resulting from the large differences in local deposition of radioactive material.

To calculate the future dose after the first year, the transfer to plants and animals depends upon many factors which will differ considerably across Europe. The estimated values of dose from ingestion of cesium isotopes should, therefore, be considered as preliminary ones that may be refined later. In Annex 1, the parameter values used and the dose

calculations are described. The results indicate that in the future, when plants will be contaminated by root uptake of Cs-137 only, the dose to humans will be about 2 μSv in regions with a deposition of 1 kBq/m^2 (Annex 1).

8.4. Total dose

The total committed effective dose equivalent, being the sum of external, inhalation and ingestion doses for the first year after the accident as reported by the various countries, is presented in Figure 14 for children. This map can be compared to the measured and modelled deposition of Cs-137, representative for ingestion in the coming years over Europe (Fig.8). The deposition maps support the estimates of the distribution of total doses over Europe. As such, for the above-mentioned higher deposition areas outside the Ukraine, i.e. with depositions of I-131 over 100 kBq/m^2 , the total committed effective dose is in the order of 1 mSv for the first year. This roughly implies a doubling of the existing background level. At some local "hot-spot" areas, where the deposition due to local rainfall was greater, the dose commitment is expected to be correspondingly higher but should eventually level out as a result of mixing local foodstuffs with those from other areas.

9. RECOMMENDATIONS

There have been differences in the nature of the measurement procedures and the manner in which data have been reported, thus causing some difficulties in interpretation. Guidance at the international level is needed on agreed methods for sample collection and the manner in which data are reported. In order to achieve a uniform assessment of data in the future, a protocol was developed and illustrated by examples.

When measurement data have been finalized, they will be reviewed in conjunction with the modelling results. Based on these results, it should be possible to verify and improve the existing transport and dispersion models.

Some inconsistencies within and between European countries were noted on the level of protective measures implemented, such as restrictions on the movement and consumption of foodstuffs. General acceptance of a pre-established methodology to provide guidance for protective actions at the national level could have obviated this situation to a larger extent. International guidelines should be developed for derived intervention levels for foodstuffs concerned. Meanwhile some international organisations like the IAEA, WHO, NEA/OECD, FAO, ECE have discussed these problems and have come up with suggestions for recommendation.

Attempts to predict the dose from ingestion in future years should be augmented by appropriate diet studies designed to account for the actual food consumption patterns. Such a program will be a direct method by which predictions from food chain models can be checked.

Guidance in the composition of geographically specific food baskets is needed to facilitate the calculation of exposures by ingestion. To avoid over-estimation of calculated exposure, particularly taking into account international trade, information must be available on an international level where public health restrictions of individual foodstuffs are concerned.

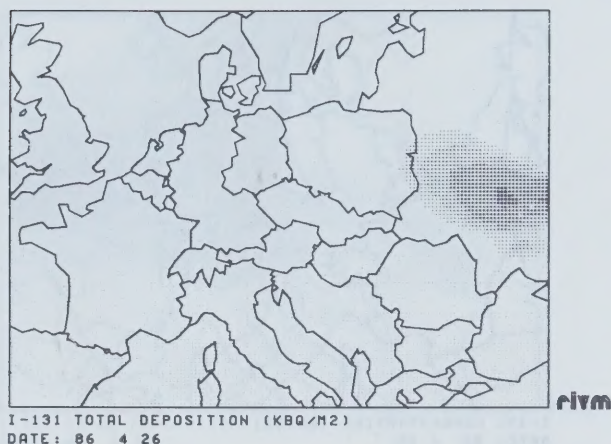
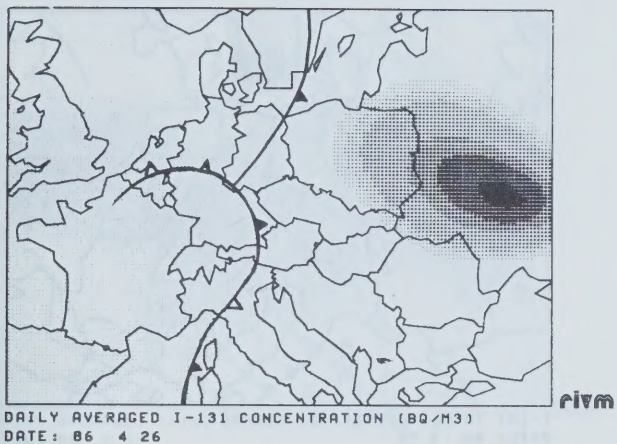


Figure 1a. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 26 April.

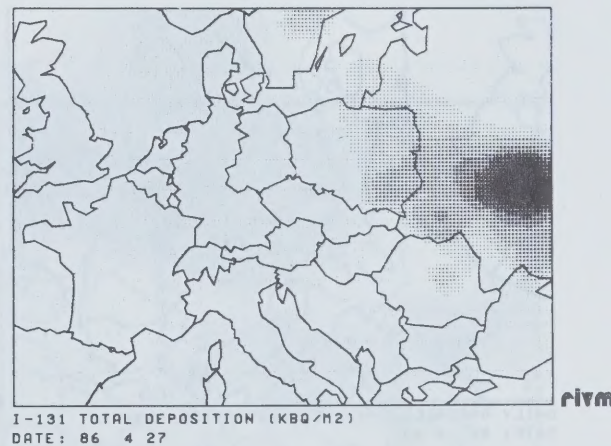
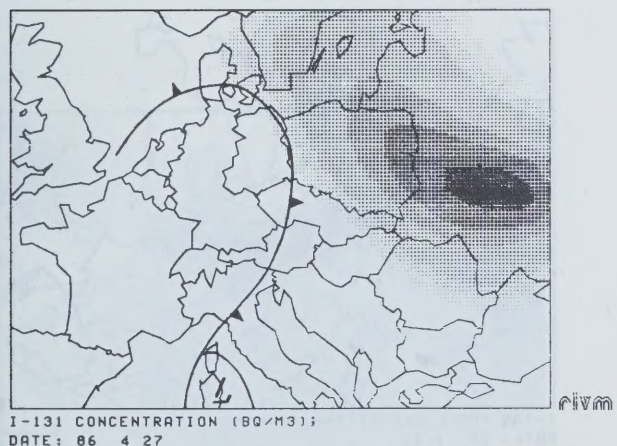
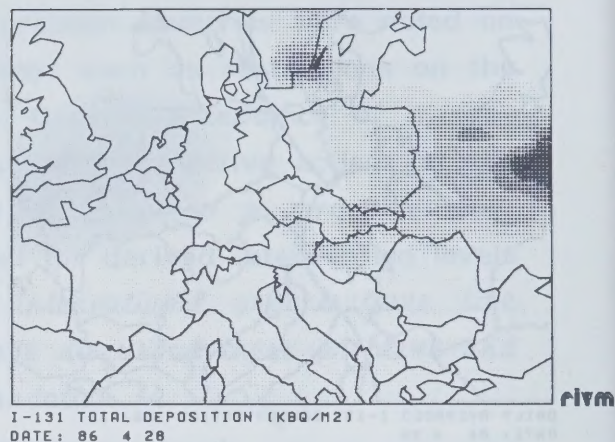
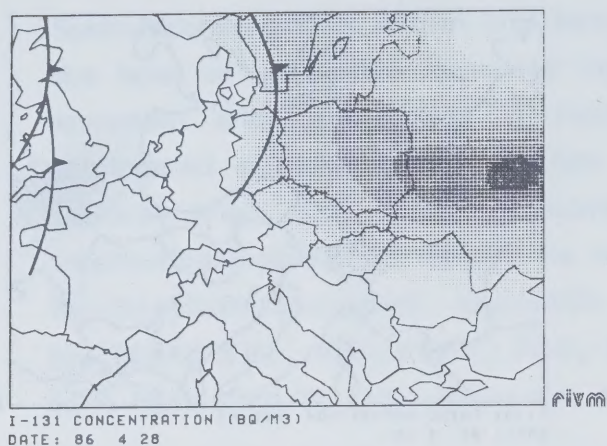
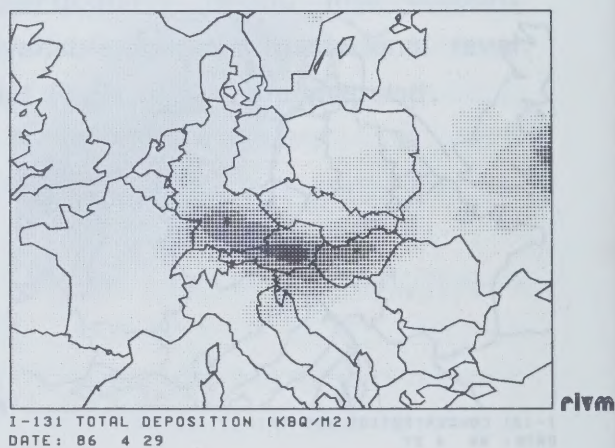
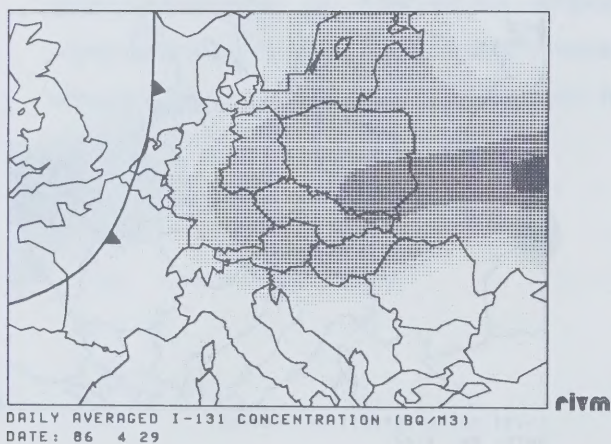


Figure 1b. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 27 April.



< 2 < 5 < 10 < 50 < 100 < 200 > 200

Figure 2a. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 28 April



< 2 < 5 < 10 < 50 < 100 < 200 > 200

Figure 2b. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 29 April.

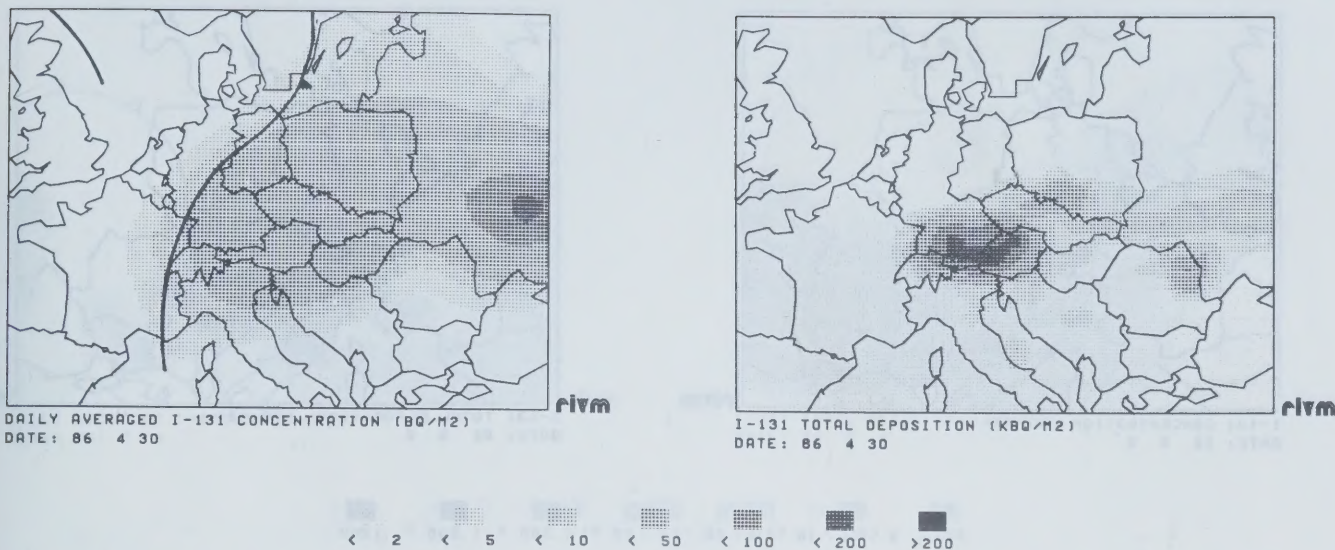


Figure 3a. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 30 April.

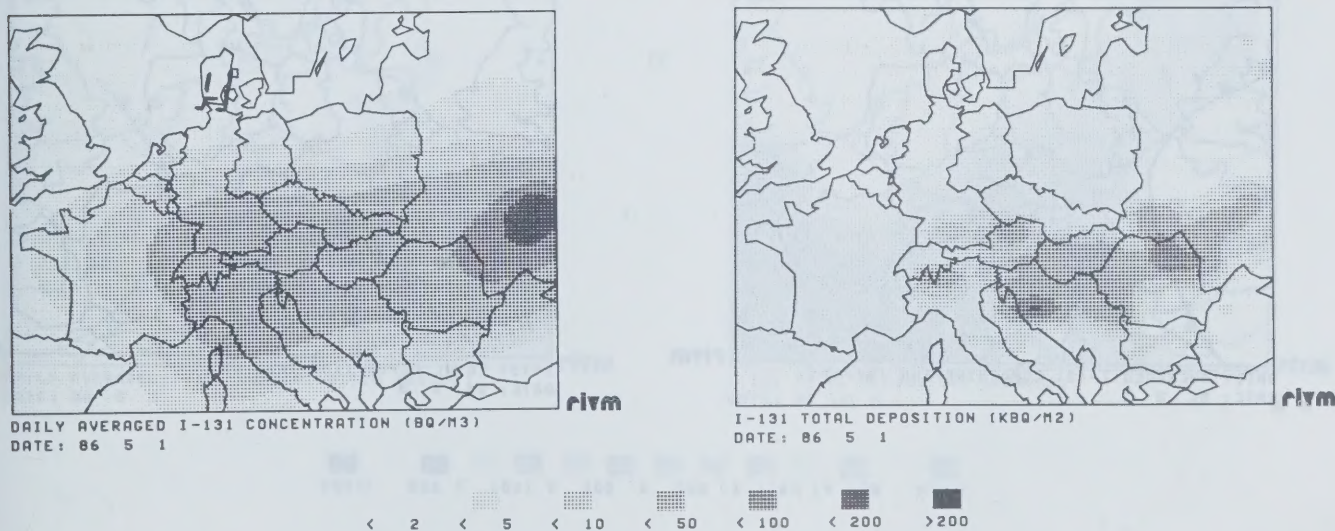
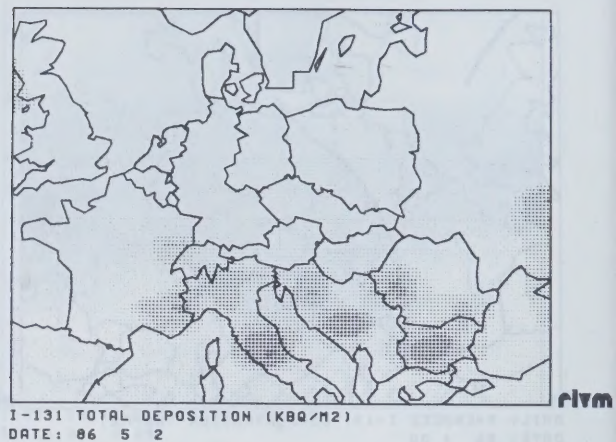
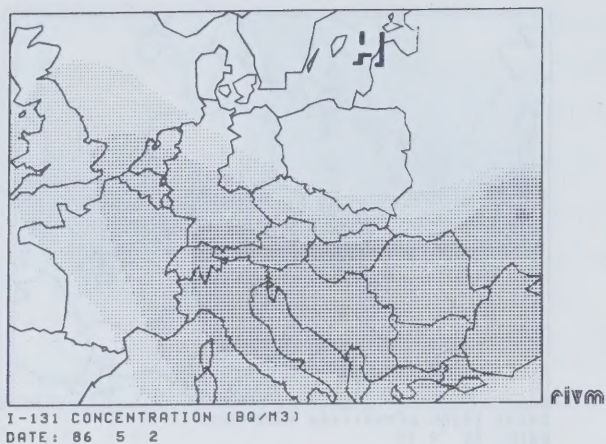
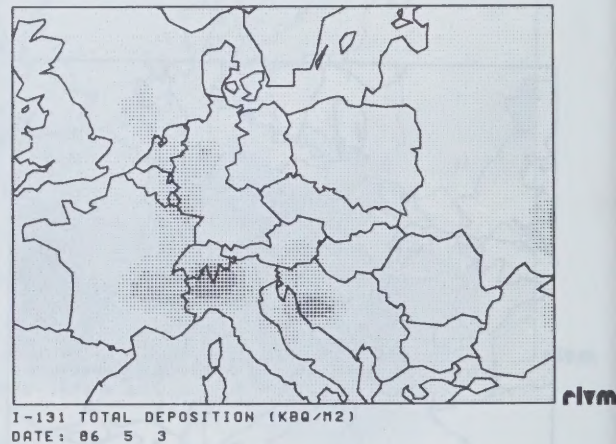
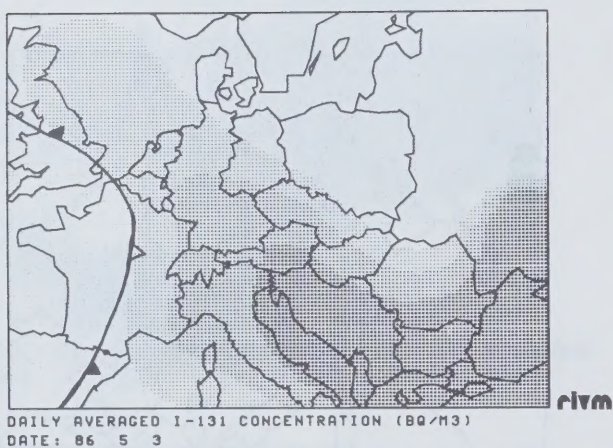


Figure 3b. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 1 May.



< 5 < 10 < 20 < 50 < 100 < 200 > 200

Figure 4a. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 2 May.



< 5 < 10 < 20 < 50 < 100 < 200 > 200

Figure 4b. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 3 May.

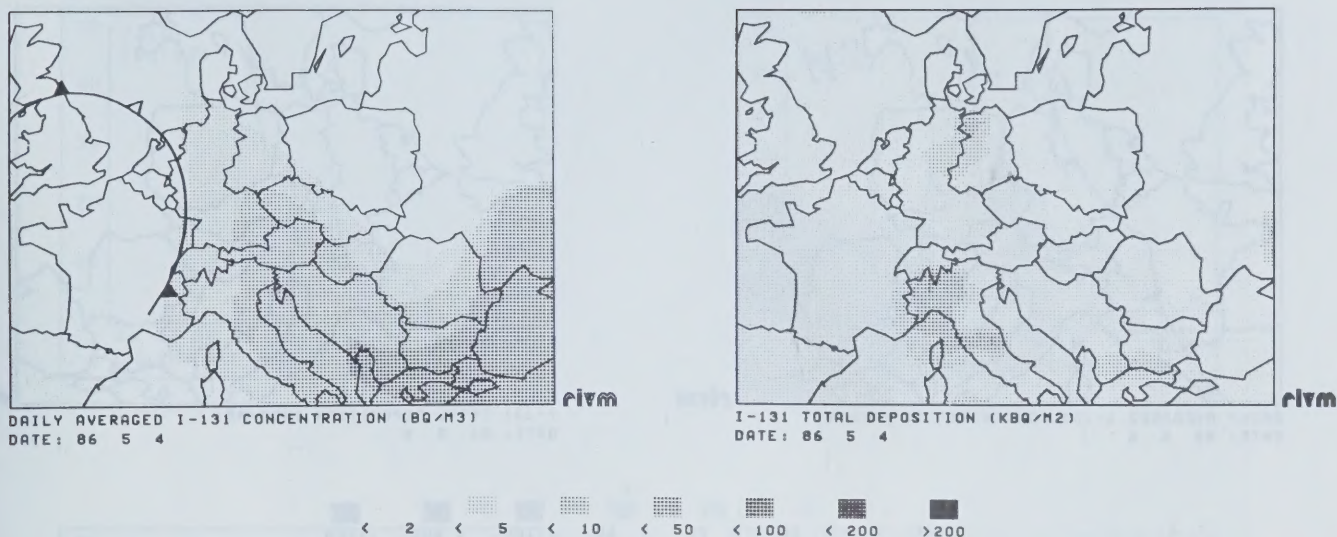


Figure 5a. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 4 May.

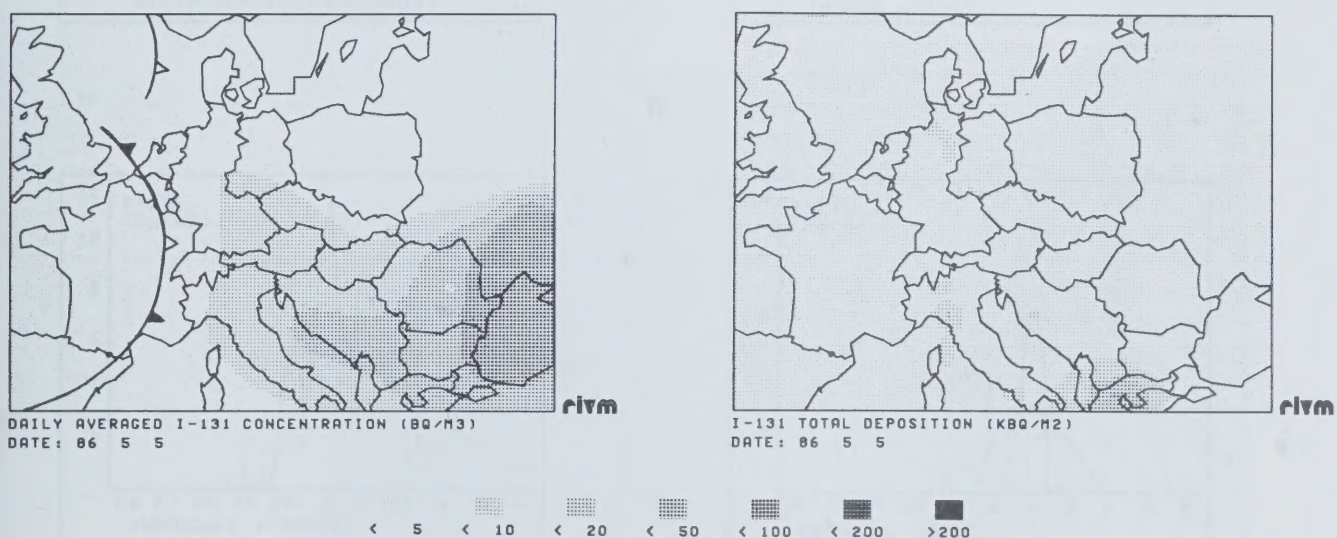


Figure 5b. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 5 May.

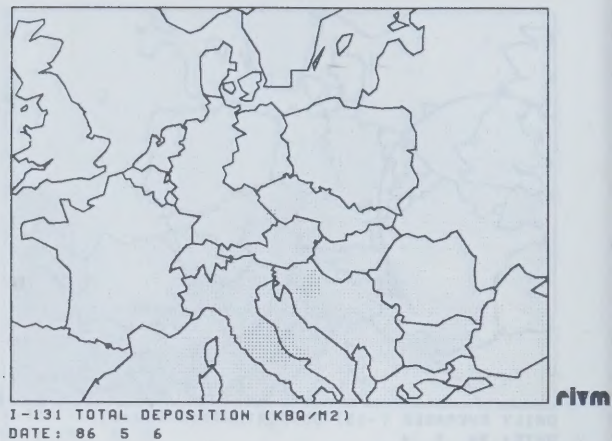
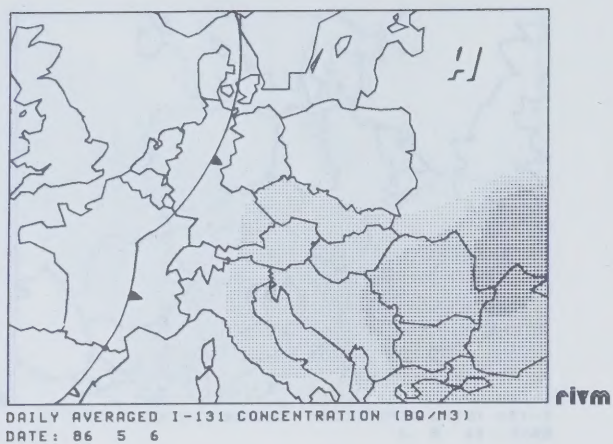


Figure 5c. Calculated daily averaged I-131 concentrations in Bq/m³ and daily depositions in kBq/m², 6 May.

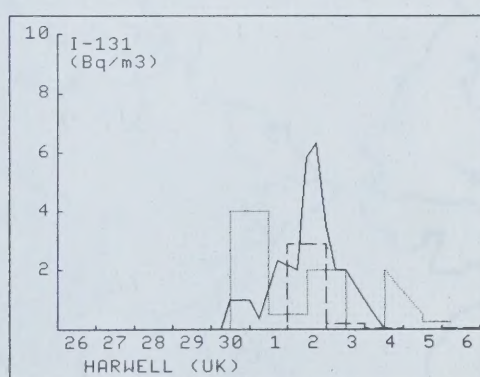
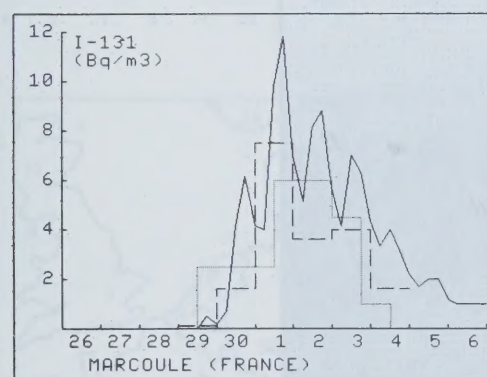
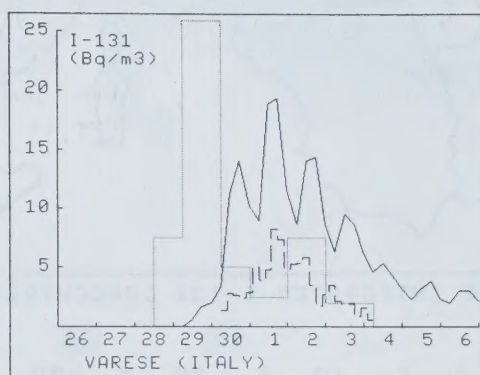
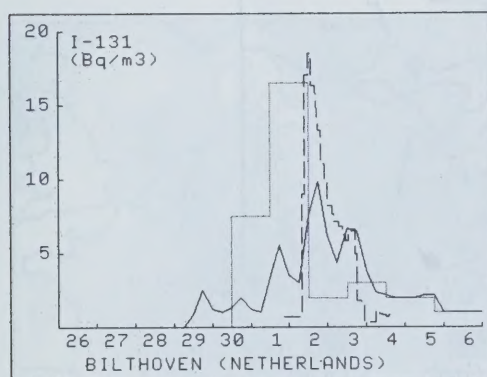
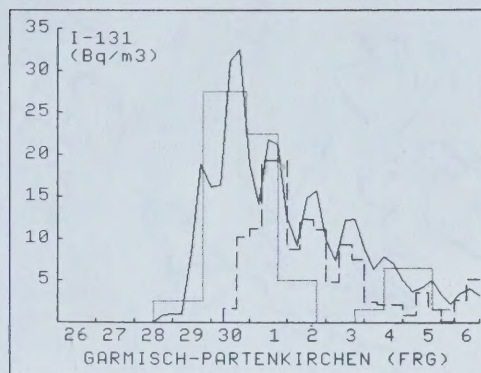
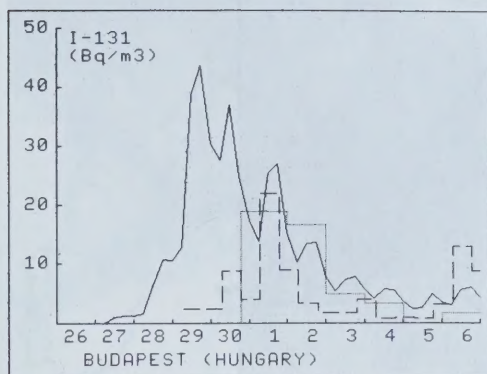


Figure 6. Calculated and measured (dashed line) I-131 concentration (Bq/m³) at European stations during the period 26 April to 6 May. Note the difference in scaling: MESOS model, dotted line; GRID model, full line; measurements, broken line.

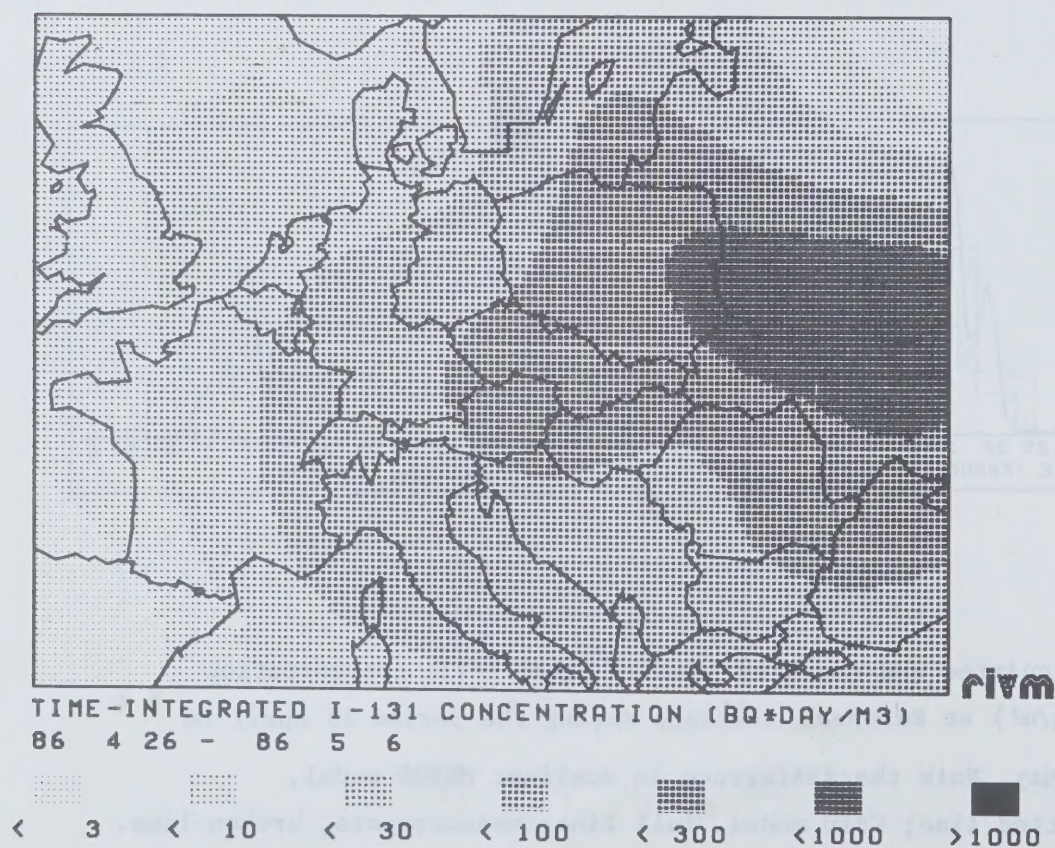
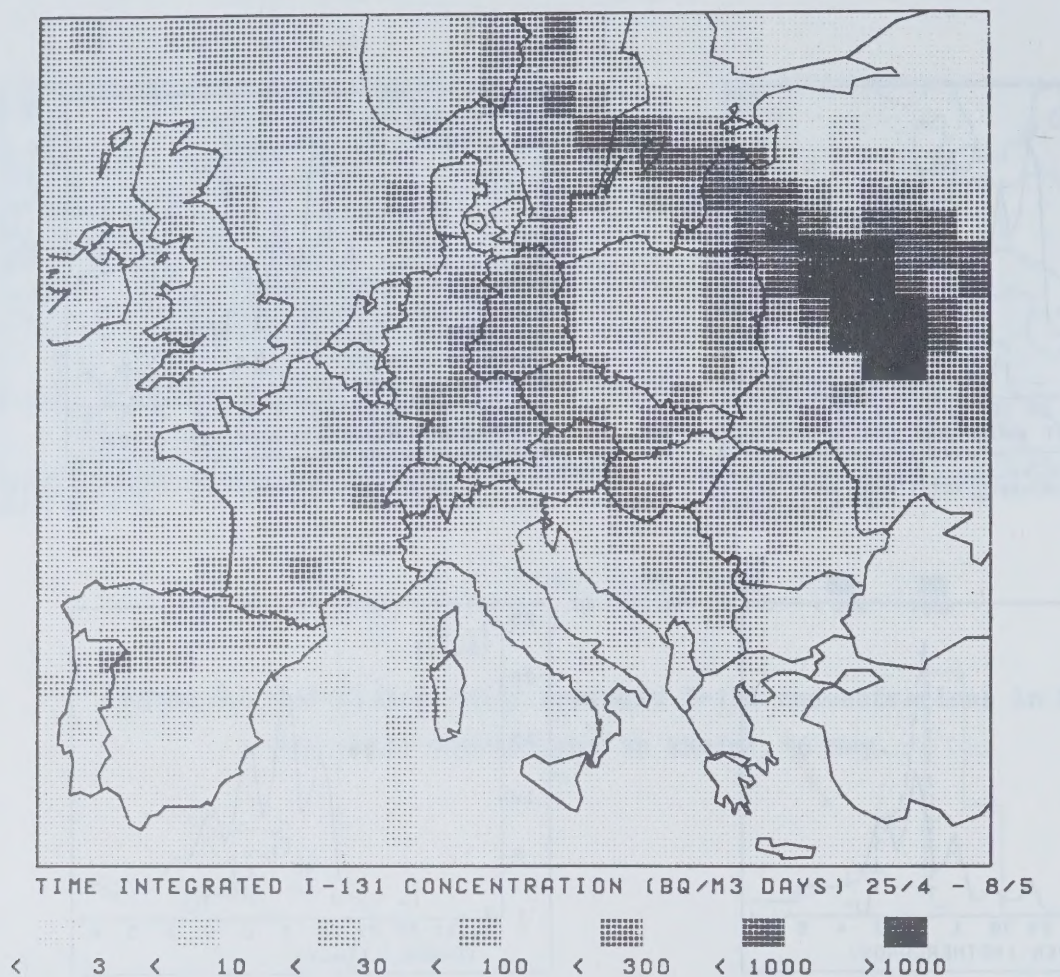


Figure 7. Time-integrated I-131 air activity concentrations, as modelled by the MESOS model (upper) and GRID model (lower).

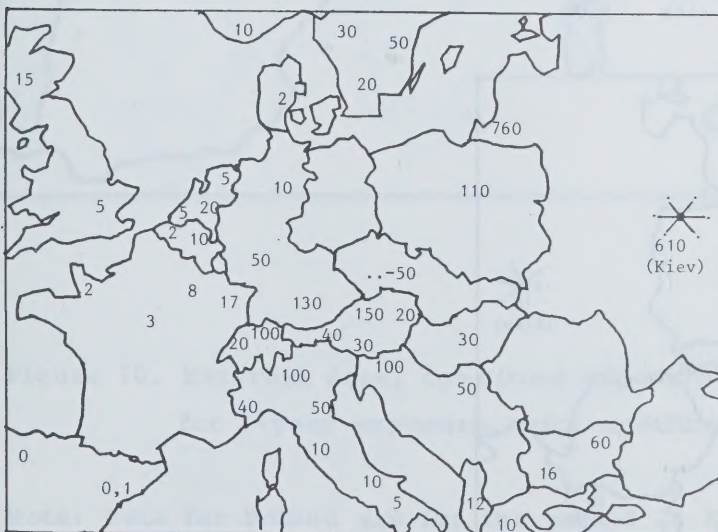
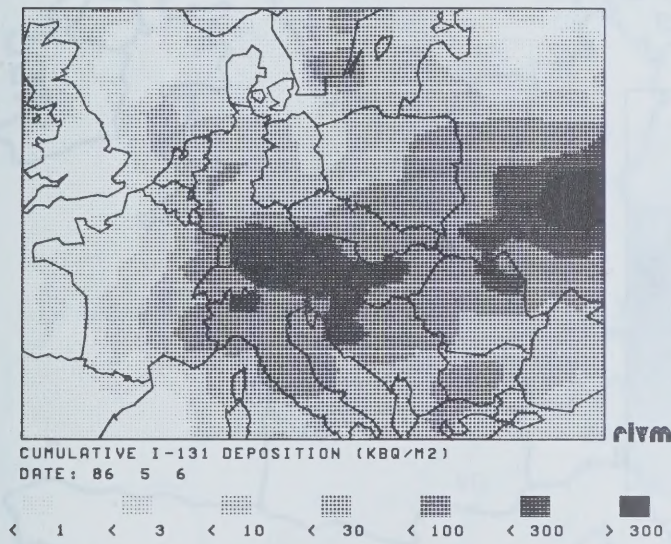
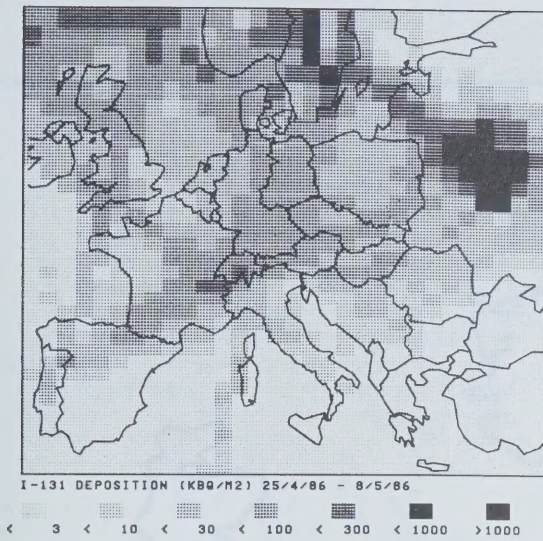


Figure 8. Accumulated I-131 deposition in KBq/m^2 as calculated by the MESOS model for the period 25 April - 8 May (upper) and by the GRID model for the period 26 April - 6 May (middle) and as measured (lower).

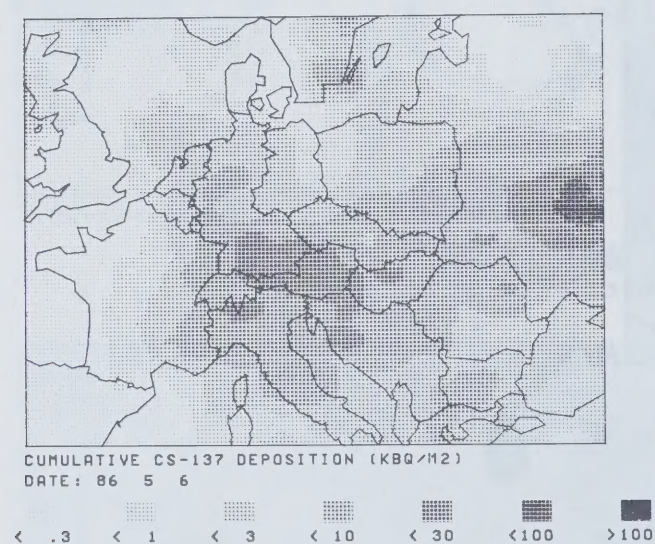
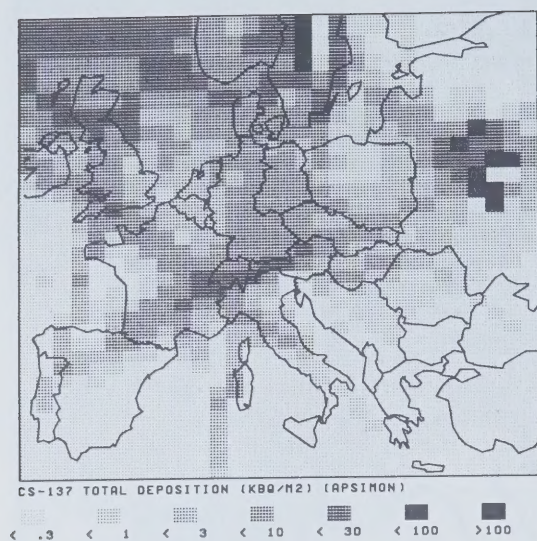


Figure 9. Accumulated Cs-137 deposition in kBq/m^2 as calculated by the MESOS model for the period 25 April - 8 May (upper) and by the GRID model for the period 26 April - 6 May (middle) and as measured (lower).



Figure 10. External dose, committed effective dose equivalent (μSv) for 1-year exposure, with modification factors.

Note: Data for Poland are for the period 28 April - 12 May only.



Figure 11. Inhalation dose for adults,
committed effective dose equivalent (μSv),
primarily from I-131.



Figure 12. Sum of inhalation and ingestion dose for children, committed thyroid dose equivalent (μSv), primarily for I-131.

Age of children

Poland	- 0-10 years
Hungary	- 4 year old
Federal Republic of Germany	- 1-10 years
France	- 1 year old
Switzerland	- 1-10 year old



Figure 13. Ingestion dose for adults, with various assumptions for periods of intake, foodstuff, and radionuclides included, committed effective dose equivalent (μSv).

Notes: Assumes locally grown food basket and local restrictions; Does not allow for dilution by non-local food of lower radionuclide levels.

Period of Intake		Food	Radionuclides
UK	- 1 year	no meat	all
France	- 1 year	no comment	all
Netherlands	- 1 year	all	all
West Germany	- 1 year	all	all
Switzerland	- 1 year	no comments	
Italy	- 1 year	milk, vegetables	Cs-137, I-131
		(modified for weathering, no restrictions accounted for)	
Finland	- 1 year	no comments	
Poland	- 28 April to 12 May	milk, vegetables	I-131
Hungary	- all years	no comment	Cs-137, I-131
Denmark	- 1 year	no comments	



Figure 14. Sum of external, inhalation and ingestion doses for children, committed effective dose equivalent (μSv).

Age of children

Poland	- 0-10 years
Hungary	- 1 year old
Federal Republic of Germany	- 0-10 years
Netherlands	- 1 year old
Italy	- 0- 1 year
Switzerland	- 0-10 years
Denmark	- 1-10 years
Austria	- 1-10 years
Finland	- 0- 1 year
UK	- 1 year

Period of exposure

Poland	- 28 April - 12 May
Hungary	- all years
Federal Republic of Germany	- 1 year
Netherlands	- 1 year
Italy	- 1 year
Switzerland	- 1 year

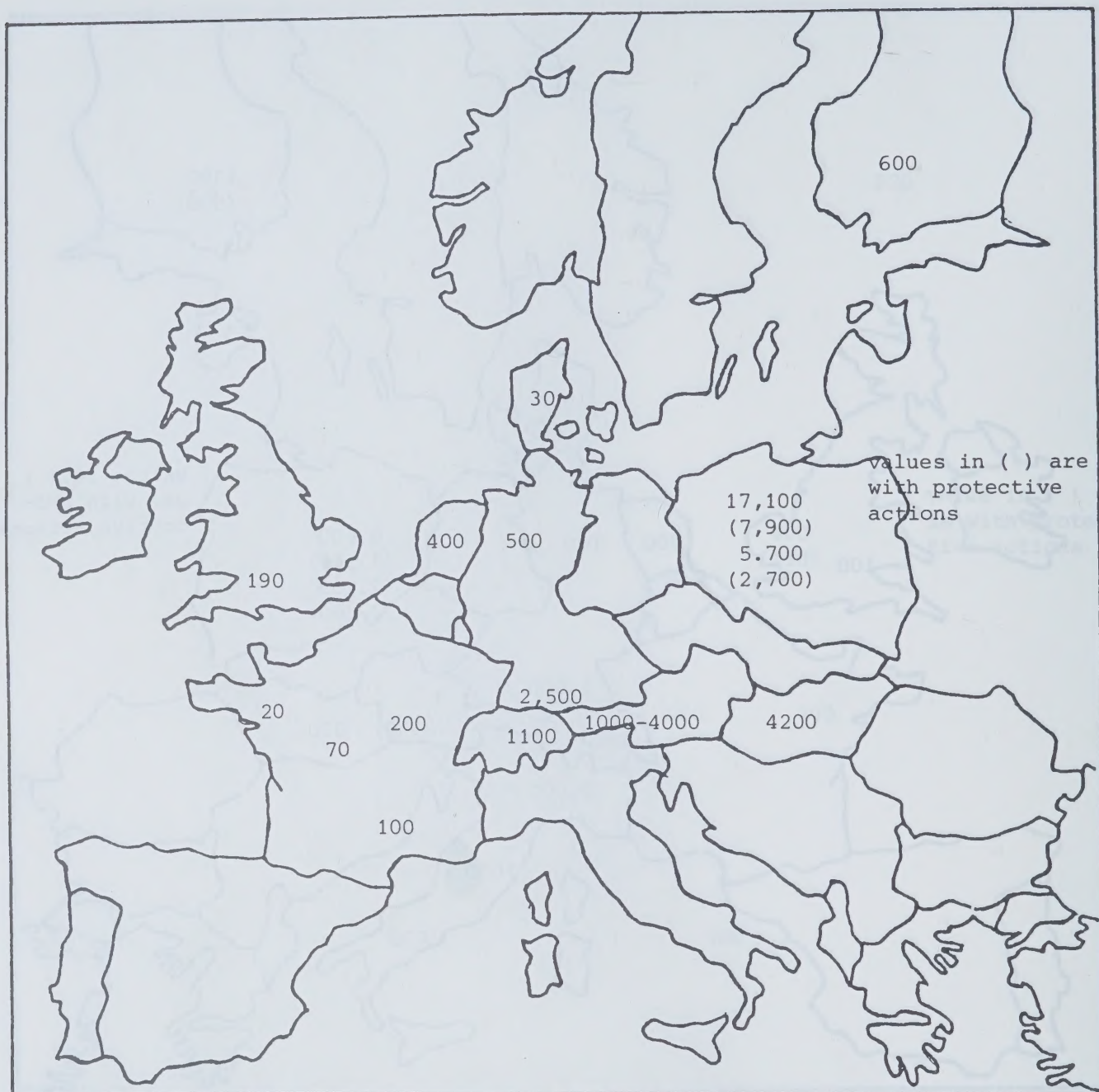


Figure 15. Sum of inhalation and ingestion doses for adults, committed thyroid dose equivalent (μSv), primarily from I-131

ANNEX 1

A. EFFECTIVE DOSE EQUIVALENT FROM EXTERNAL IRRADIATION

The effective dose equivalent can be calculated from:

- the measured kerma rate in the air at 1 m above the surface;
- the measured deposition of radionuclides on the ground.

The procedure to calculate the effective dose equivalent from the measured kerma rate in air is to integrate the values over time, and then convert the sum to the effective dose equivalent by using a factor of 0.7. The procedure to calculate the effective dose equivalent from measured deposition of radionuclides on the ground is to apply "gamma dose factors for ground contamination" according to Table 1. Table 2 gives an example for calculating the effective dose equivalent from the measured kerma rate in air. In addition to Table 2, the procedure of calculation is as follows:

External radiation: air kerma

There are three time periods of concern:

1. Plateau (from 1 to 3 May)

$$\text{The dose} = 1.0 \times 24 \times 2 \approx 50 \text{ } \mu\text{Gy}$$

2. The 1st exponent (till 10 May, $T_{1/2} = 5$ days).

$$\text{The dose} = \int_0^8 1.0 \times 24 \times e^{-\frac{0.693}{5}t} dt =$$

$$- 24 \times \frac{5}{0.693} (1 - e^{-\frac{0.693 \times 8}{5}}) = 173 \times (1 - e^{-1.1}) =$$

$$173 \times 0.67 \approx 116 \text{ } \mu\text{Gy}.$$

3. The 2nd exponent (from 10 May to 15 June, $T_{1/2} = 22$ days)

$$\text{The dose} = \int_0^{30} 0.4 \times 24 \times e^{-\frac{0.693}{22} t} dt =$$

$$305 \times (1 - e^{-1.15}) = 305 \times 0.7 = 214 \mu\text{Gy}.$$

If integration is extended from 10 May to infinity, the dose is 305 μGy .

Thus the total dose from 1 May to 15 June is:

$$50 + 116 + 214 \mu\text{Gy} = 380 \mu\text{Gy}$$

and from 1 May integrated to infinity:

$$50 + 120 + 305 = 475 \mu\text{Gy}$$

The EDE are:

$$(1 \text{ May} - 15 \text{ June}) \quad 390 \times 0.7 = 270 \mu\text{Gy}$$

$$(1 \text{ May} - \text{infinity}) \quad 475 \times 0.7 = 330 \mu\text{Gy}$$

Table 3 gives an example for calculating the effective dose equivalent rate from measured deposition of radionuclides. The dose is the product of the dose rate and the physical lifetime of the radionuclides.

B. DOSE FROM INHALATION OF IODINE-131

B.1 Calculations from measured air concentrations

The total inhaled activity of I-131 is calculated from the measured values of the activity concentration. These calculations have to be performed separately for adults and children.

The corresponding breathing rates are accepted as ¹:

1 year, $3.8 \text{ m}^3/\text{d}$;

adult, $23 \text{ m}^3/\text{d}$

The corresponding conversion factors to calculate the dose equivalent from I-131 inhaled are:

dose equivalent in thyroid:

1 year, $2.2 \cdot 10^{-3} \text{ mSv/Bq}$

adult, $2.7 \cdot 10^{-4} \text{ mSv/Bq}$

effective dose equivalent:

1 year, $6.6 \cdot 10^{-5} \text{ mSv/Bq}$

adult, $8.1 \cdot 10^{-6} \text{ mSv/Bq}$

An example is given in Table 4. The results of calculation are as follows:

	thyroid dose (mSv)	eff.dose equivalent (μSv)
1 year	0.9	28
adult	0.7	21

B.2 Calculation from body measurement

Table 5 gives data on whole-body measurements of children between 6 and 9 years of age 4 days after the arrival of the radioactive plume. The average total body activity of I-131 is 420 Bq. The children lived in the area where the activity concentration in air changed with time. Assuming that I-131 intake was only by inhalation, the total intake is $112 \text{ Bq d/m}^3 \times 15 \text{ m}^3/\text{d} \times 0.5 = 840 \text{ Bq}$.

¹ Report of the Task Force on Reference Man. Oxford, Pergamon Press, 1975 (International Commission on Radiological Protection, Publication 23).

The inhalation rate for 10-yr-old children is $15 \text{ m}^3/\text{d}$ and the factor 0.5 takes into account that 50% of the inhaled activity is exhaled immediately. Since no allowance was made for the radioactive decay, the calculated value is higher than the measured one. The difference, however, is not significant in view of the simplifications made.

TABLE 1: GAMMA DOSE FACTORS FOR GROUND CONTAMINATION

Nuclide	g_b [Gy(Bq.s.m ⁻²) ⁻¹]		Nuclide	g_b [Gy(Bq.s.m ⁻²) ⁻¹]	
		EE			EE
H-3	0		I-129	5.7	17
C-14	0		I-131	3.0	16
F-18	7.3	16	I-132	1.5	15
Na-22	1.4	15	I-133	3.8	16
Na-24	2.4	15	I-135	1.6	16
P-32	0		Cs-134	1.1	15
Cr-51	2.0	17	Cs-137 Ba-137m	3.8	16
Mn-54	5.9	16	Cs-138	1.4	15
Fe-55	0		Ba-140	1.6	16
Fe-59	7.8	16	La-140	1.4	15
Co-58	5.9	16	Ce-141	6.5	17
Co-60	1.6	16	Ce-144	2.0	17
Zn-65	5.1	16	Pr-144	1.9	17
Rb-88	4.6	16	Ce-144 Pr-144	3.8	17
Sr-89	0		Np-239	8.6	17
Sr-90	0		Pu-238	2.4	17
Y-90	0		Pu-239	1.7	18
Sr-90 Y-90	0		Pu-240	0	
Sr-91	6.8	16	Pu-241	0	
Y-91	2.4	18	Am-241	1.6	17
Sr-91 Y-91	6.8	16	Am-243	3.2	17
Zr-95	5.1	16	Am-244	5.9	16
Nb-95	5.4	16	Cm-242	0	
Mo-99	1.1	16	Cm-243	8.6	17
Tc-99m	8.4	17	Cm-244	0	
Ru-103	4.1	16			
Ru-106 Rh-106	1.4	16			
Ag-110m	1.9	15			
Sb-124	1.2	15			
Sb-125	3.8	16			

**TABLE 2: AIR KERMA RATES FROM EXTERNAL RADIATION
AS A FUNCTION OF TIME**

DAY AND TIME OF MEASUREMENT	$\mu\text{Gy/h}$
<u>30.4.86</u>	
12.00	0.18
14.30	0.21
16.00	0.98
19.00	0.95
<u>01.05.86</u>	
07.00	1.05
12.00	1.00
16.00	0.98
<u>02.05.86</u>	
11.00	0.95
14.30	1.00
17.45	1.00
<u>03.05.86</u>	
14.30	0.90
18.00	0.78
<u>04.05.86</u>	
07.00	0.78
16.30	0.74
<u>05.05.86</u>	
11.00	0.64
18.20	0.61
<u>06.05.86</u>	
11.30	0.58
17.30	0.56

TABLE 2: (continued)
AIR KERMA RATES FROM EXTERNAL RADIATION
AS A FUNCTION OF TIME

DAY AND TIME OF MEASUREMENT	$\mu\text{Gy/h}$
<u>07.05.86</u>	
16.00	0.52
<u>08.05.86</u>	
15.00	0.45
<u>09.05.86</u>	
08.00	0.41
<u>11.05.86</u>	
15.30	0.34
<u>14.05.86</u>	
20.15	0.31
<u>19.05.86</u>	
15.45	0.24
<u>23.05.86</u>	
11.40	0.21
<u>01.06.86</u>	
10.30	0.17
<u>09.06.86</u>	
10.00	0.13
<u>16.06.86</u>	
14.00	0.14

TABLE 3: CALCULATION OF EXTERNAL RADIATION
(hypothetical example)

Assumption: Deposition within short time

Nuclide	Deposition (kBq/m ²)	Conversionfactor (Gy·Bq ⁻¹ ·s ⁻¹ ·m ²)	Dose rate (max) (nGy/h)	Dose (μGy)	
Ru-103	2.8	4.1	E-16	4	52
I-131	7	3.0	E-16	7.8	2
I-132	7	15	E-16	38	11
Cs-134	0.7	11	E-16	3	79
Cs-137	1.4	3.8	E-16	2	754
Total:			55	900	

Calculation for I-131:

$$7 \text{ (kBq/m}^2\text{)} \times 10^3 \left(\frac{\text{Bq}}{\text{kBq}} \right) \times 3.10^{-16} \text{ (Gy} \cdot \text{Bq}^{-1} \cdot \text{s}^{-1} \cdot \text{m}^2\text{)} \times 3600 \left(\frac{\text{s}}{\text{h}} \right)$$

$$\times 10^9 \frac{\text{nGy}}{\text{Gy}} = 7.6 \frac{\text{nGy}}{\text{h}} .$$

Conversion factors from IAEA Safety Series 57¹.

Measured maximum dose rate: 50 nGy/h

¹ Generic models and parameters for assessing the environmental transfer of radionuclides from routine releases. Vienna, International Atomic Energy Agency, 1982 (IAEA Safety Series 57).

TABLE 4: **MEASUREMENT OF I-131 IN AIR**
 (Hypothetical example)

DAY	Concentration Bq/m ³
29.04.86	3.1
30.04.	52
30.04.	34
30.04.	30
01.05.	48
01.05.	38
01.05.	24
02.05.	16
02.05.	13
02.05.	10
03.05.	5.7
04.04.	3.5
05.05.	1.6
06.05.	2.6
07.05.	9.8E-01
08.05.	1.1E-01
09.05.	1.2E-01
10.05.	9.4E-02

TABLE 4: (continued)
MEASUREMENT OF I-131 IN AIR
 (Hypothetical example)

DAY	Concentration Bq/m ³
11.05.	2.9E-02
12.05.	5.7E-02
13.05.	2.4E-02
15.05.	1.4E-02
21.05.	4.9E-03

TABLE 5: WHOLE-BODY MEASUREMENTS OF CHILDREN BETWEEN 6 AND 9 YEARS OF AGE 4 DAYS AFTER ARRIVAL OF THE RADIOACTIVE PLUME AT A PLACE WITH AN INTEGRATED CONCENTRATION OF 112 Bq I-131 d/m³ IN AIR

DATE OF MEASUREMENT	AGE	SEX	TOTAL BODY I-131 (Bq)
04.05.86	6.5	F	460
04.05.86	7	M	440
04.05.86	9	M	420
04.05.86	7	M	370
Average			420 Bq

Table 6: VALUES FOR B_V FOR CESIUM

Product type	Expected values	B_V		Average
		Min. value	Max. value	
cereals	0.01	0.001	0.05	0.80
Pods, beans	0.04	0.004	0.20	0.20
root crops (incl. potatoes)	0.02	0.002	0.10	0.25
leafy vegetables	0.07	0.007	0.50	0.15
fodder and grass	0.3	0.05	1.0	0.25

The contamination of beef and milk can be calculated by:

$$C_{\text{milk}} = 0.008 \text{ d/l} \times C_{\text{grass, fodder}} \text{ Bq/kg} \times 15 \text{ kg/d}$$

$$C_{\text{beef}} = 0.02 \text{ d/kg} \times C_{\text{grass, fodder}} \text{ Bq/kg} \times 15 \text{ kg/d}$$

The uncertainty factor is about 3. The contamination of sheep products is about a factor of 10 higher. The contamination of goat products is higher than of cow products but considerably lower than of sheep products.

Assuming an average deposition of Cs-137 of 1 000 Bq/m², the results of the calculation of food contamination and the yearly Cs-137 intake rate are compiled in Table 7. The yearly intake rate of Cs-137 will be about 100 Bq in the years following the current one which corresponds to an EDE of 1.4 μSv (Table 7).

Table 7: ACTIVITY OF CS-137 IN DIFFERENT FOODSTUFFS AND THE YEARLY INTAKE OF CS-137 WHEN THERE IS ONLY ROOT UPTAKE ASSUMING AN AVERAGE DEPOSITION OF CS-137 OF 1000 Bq/m²

	Cs-137 Activity (Bq/kg fresh weight)	yearly intake rate (kg)	total Cs-137 intake (Bq/year)
cereals	0.03	100	3
pod, beans	0.03	50	1.5
root crops (including potatoes)	0.02	100	2
leafy vegetables	0.04	10	0.4

fodder, grass	0.6		

milk	0.3	150	45
beef	0.7	70	50

C. CALCULATION OF THE FOOD CONTAMINATION IN FUTURE

The contamination of food in the years following the current one resulting from the Chernobyl accident will mainly be caused by Cs-137, which is present in the soil and will be taken up via the roots by food and animal feed crops. For these products, the contamination (C) can be calculated by:

$$C = B_V \times Q \times d / m$$

in which B_V = concentration ratio of Cs-137 and/or Cs-134 in crop and in soil

Units: (activity per kg dry crop)

(activity per kg dry soil)

Q = contamination of the soil in Bq/m²

d = average dry matter fraction of crop (dimensionless)

C = contamination of food and animal feed crop in Bq per
kg fresh product

m = mass of soil in the root zone (250 kg for crops,
125 kg for pasture)

In Table 6, the values for the concentration ratio of Cs-137 and Cs-134 in crops and in soil are compiled. The minimum and maximum values represent a 95% confidence interval. All values do not take into account seasonal variations, sample plot variations and variations within a product type (e.g. within the leafy vegetable group the differences between spinach, cabbage and lettuce are not taken into account). The uncertainty, i.e. the range is large, can be reduced by taking into account specific data for different types of soil, the pH, the organic matter content and other variables.¹

¹ Heisterkamp, S.H. & Köster, T. Results of reanalysis of data from the IUR workshop on plant-to-soil transfer factors. Appendix to the 5th report of the Working Group on Soil-to-Plant Transfer Factors. Bilthoven, National Institute of Public Health and Environmental Hygiene, 1986.

D. PROTECTIVE MEASURES:

Calculation of the dose equivalent in the northeast part of Poland

The data summarized in Table 8 are based on a study which involved 1400 adults and children (ages 0 to 10 years).

External radiation was calculated, as stated in the protocol, on the basis of external kerma rates estimated between 28 April and 12 May and computed integral air kerma.

Internal dose from inhalation was calculated assuming that I-131 was the principal radionuclide. Air concentration of iodine (Bq/m^3) estimated between 28 April and 12 May served to integrate inhalation activity. Ingestion activity and resultant dose equivalent were measured on the basis of food contamination in the period 28 April to 12 May, taking into account a food basket typical for the country.

Protective measures included:

- a) administration of stable iodine (70 mg) on 29 April;
- b) fresh milk was totally banned for children up to 3 years old and replaced by powdered milk;
- c) use of milk with radioactivity above 1000 Bq/l was banned;
- d) grazing cows on pasture or providing them with fresh fodder was banned countrywide until 12 May.

Table 8: DOSE EQUIVALENTS IN THE NORTHEAST PART OF POLAND AFTER
THE CHERNOBYL ACCIDENT (CALCULATED ON THE BASIS OF RADIOACTIVE
IODIDES AND CESIUM) DATA COLLECTED BETWEEN 28 APRIL AND 12 MAY

Dose equivalents (μSv)		Dose equivalents (μSv) with protective measures			
without protective measures		adults		children	
		adults		children	
		thyroid	EDE	thyroid	EDE
external radiation		-	0.44	-	0.46
inhalation		3.6	0.11	25.0	0.75
ingestion		13.5	0.40	180.0	5.4
		17.1	0.95	205.0	6.61
		7.9	0.68	35.0	1.51

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